A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

Renewable Energy Potential in the USA and Mexico

Ralph P. Overend

Building the Renewable Energy Market in North America

North American Commission for Environmental Cooperation
28–29 October 2004, Montréal, PQ, Canada

Outline

- Actual Renewable Energy Contribution
  - USA, Canada and Mexico
- Forecasts
- Issues
  - Resource Assessment
  - Technology
  - Growth rates

North America – 3 Nations Statistics

Country	Pop'n	GDP	TPES	Electric	CO_2
Units	Million	T$ PPP	EJ	TWh	Mt
Canada	31.4	843.1	10.5	532	532
Mexico	100.4	819.8	6.6	184	365
USA	287.5	9196	95.9	3802	5652

TPES = Total Primary Energy Supply

PPP = Purchasing Power Parity

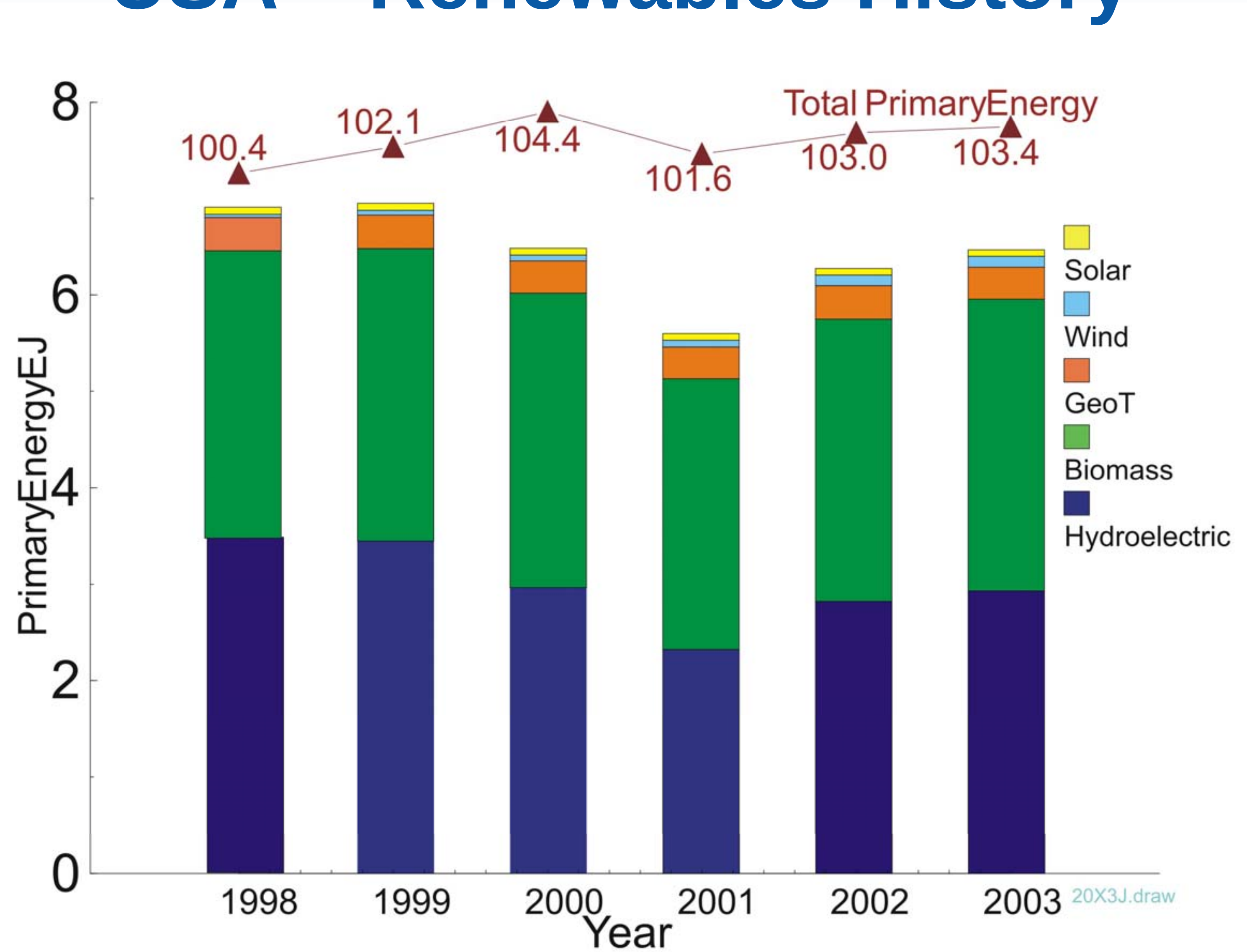
Source: IEA Key World Energy Statistics 2004 with data from 2002

North America – 3 Nations Statistics

Country	Energy/ person	Energy unit GDP	Renewable Share TPES	Electric
Units	**GJ/*cap***	**kJ/ $PPP**	**%**	**%**
Canada	**333**	**12.4**	**17**	**57**
Mexico	**66**	**8**	**12.2**	**15.1**
USA	**333**	**10.4**	**6**	**8.9**

Sources: IEA *Key World Energy Statistics 2004 with data from 2002*, DOE/IEA *Renewable Energy Trends* 2003, DOE/EIA *Mexico Country Analysis Brief (2004*), *Renewable Energy in Canada Status Report 2002* - A National Report prepared for the Renewable Energy Working Party (REWP) of the International Energy Agency (IEA) Office of Energy Research and Development Natural Resources Canada

USA – Renewables History



NREL National Renewable Energy Laboratory

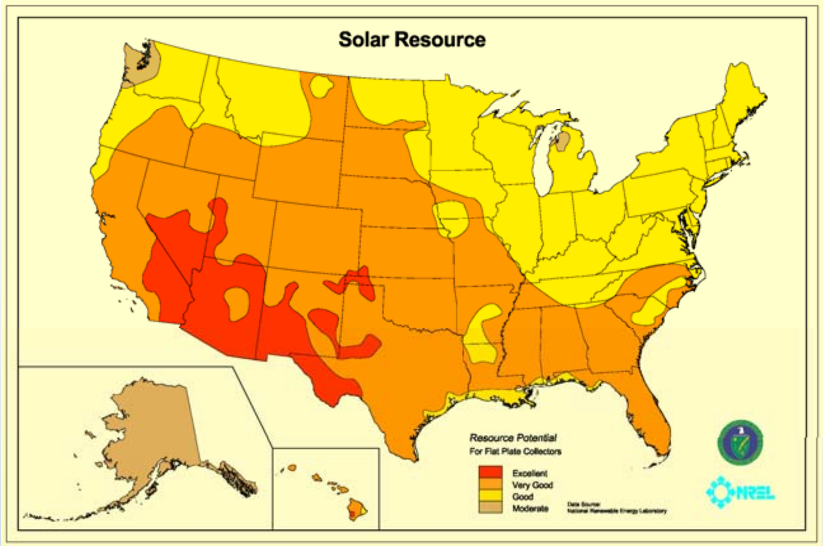
Renewables can meet the Global Need

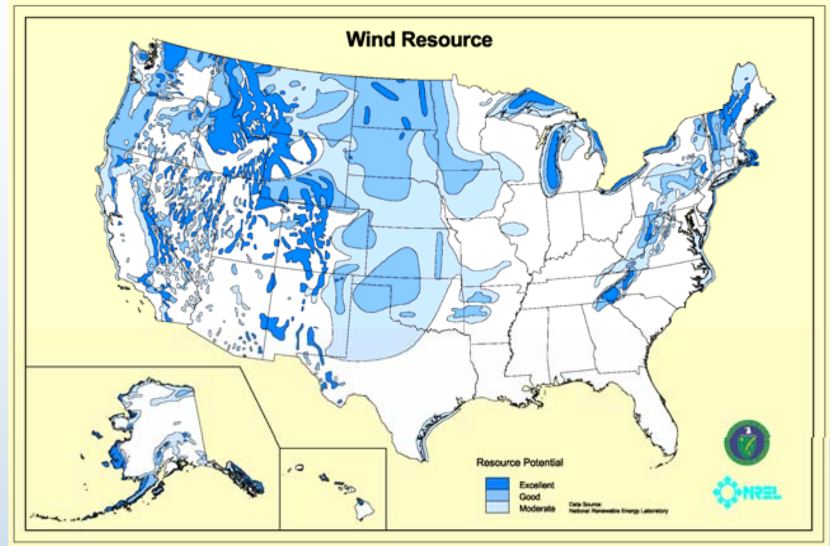
REN Wm^{-2}	Flux	Capture
Solar	230	20
Wind	25	5
Biomass		0.5-1

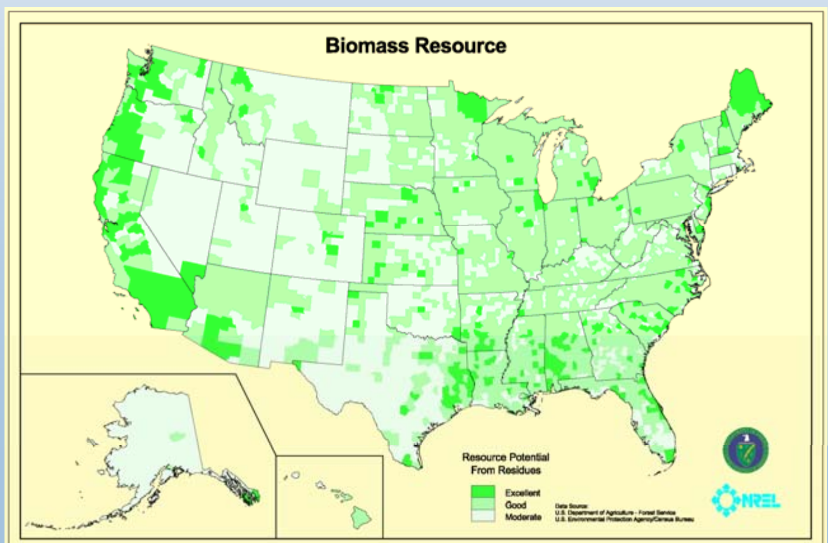
Year	2002	2050	
TPES TW	Total	Total	NonC
350 ppm	12	30-50	>30
450ppm			25
550 ppm			15

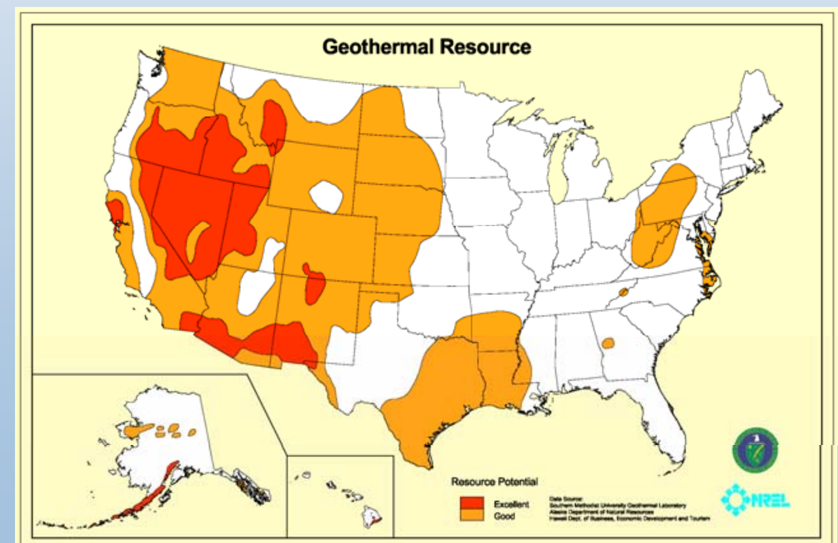
- Solar – 10 TW = 220,000 km^2
  - 500 km rectangle e.g. 1/3 Alberta, or Minnesota
- Wind – 10 TW = 2,000,000 km^2 (Class IV)
  - Large areas of local concentration > Class IV
- Biomass 10 TW = 10 – 15 M km^2 or
  - 10% of world land area 131 M km^2 = Today's agriculture
  - CAN + USA + MEX = 16% of world land area at 21 M km^2

U.S. Renewable Energy Resources

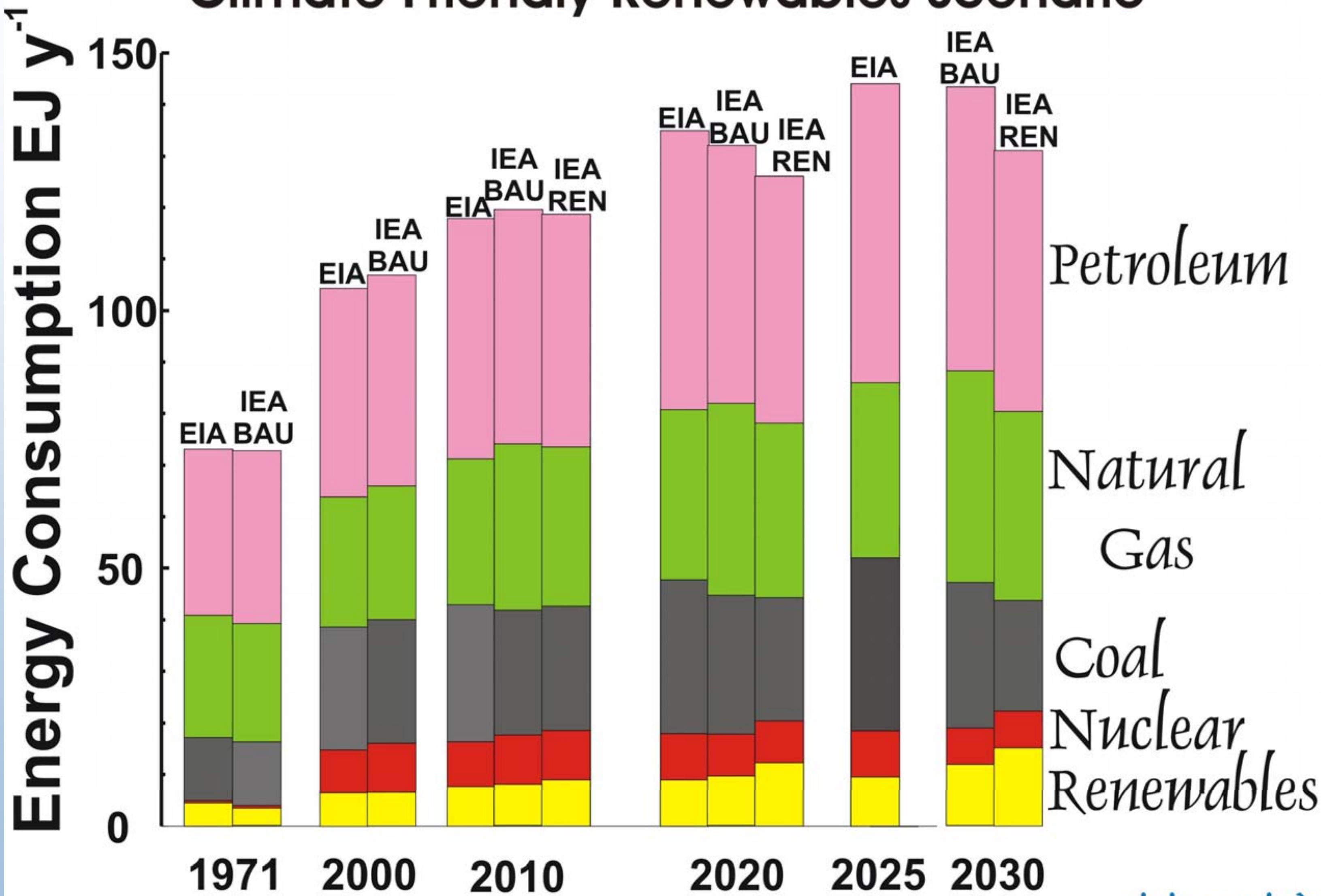








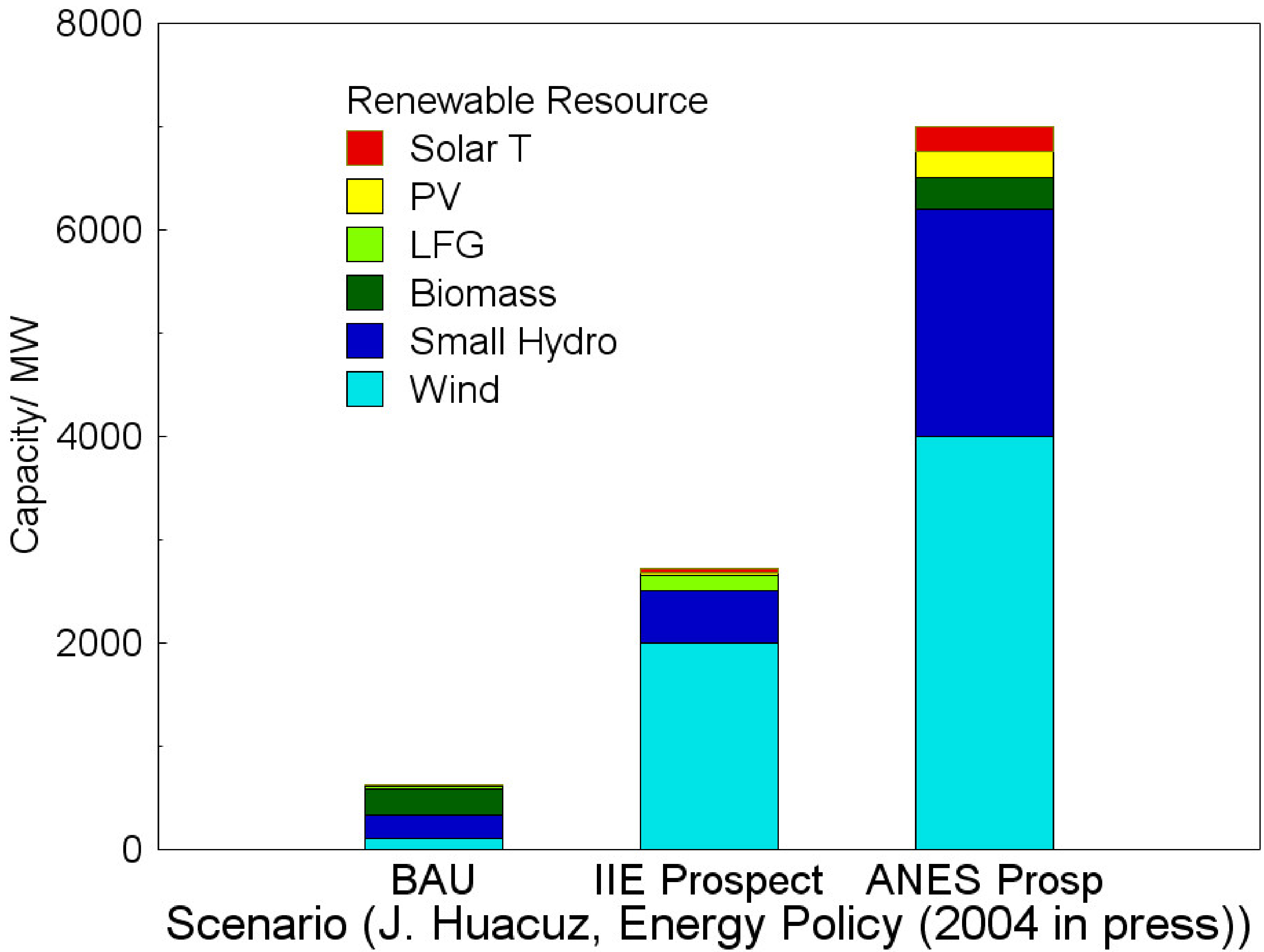
Energy Futures - Two Business as Usual and a Climate Friendly Renewables Scenario



Source: AEO 2004, and World Energy Investment Outlook 2003 insights

eiaieaproj.cdr

Mexico Decade Projections



Wind Expansion

- US Resource
  - Class IV (50 States)
  - 812 GW
  - Equivalent to USA 2000
- WinDS Model
  - Installs T&D & Generation according to least cost.
  - Incorporates
    - AEO cost forecasts
    - Technology Improvement

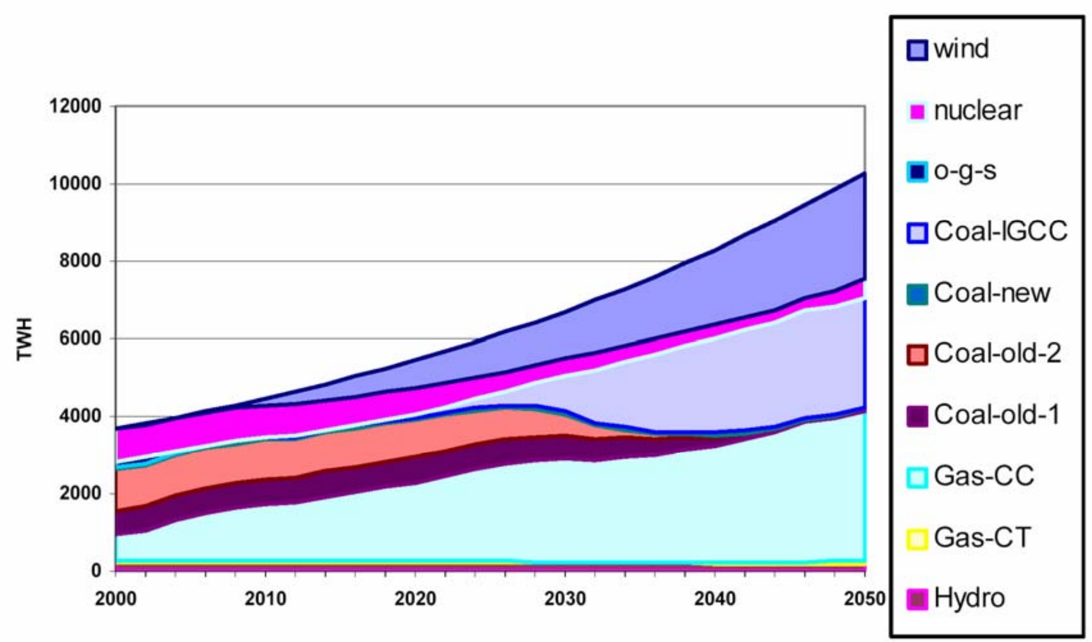


Chart 2: Base-Case Generation

Source: MN Schwartz, DL Elliott, GL Gower *Gridded state maps of wind electrical potential* . AWEA Windpower 92 proceedings (1992); W Short, N. Blair, S Heimiller. *Long term potential of wind power in the United States*. Solar Today November/December 2003 NREL/JA-620-34871

Wind Energy

GE Wind's 1.5 megawatt wind turbine installed in Tehachapi, California

Vestas V-47 Turbines on wind farm in Kansas

11193

Brazilian hybrid power system

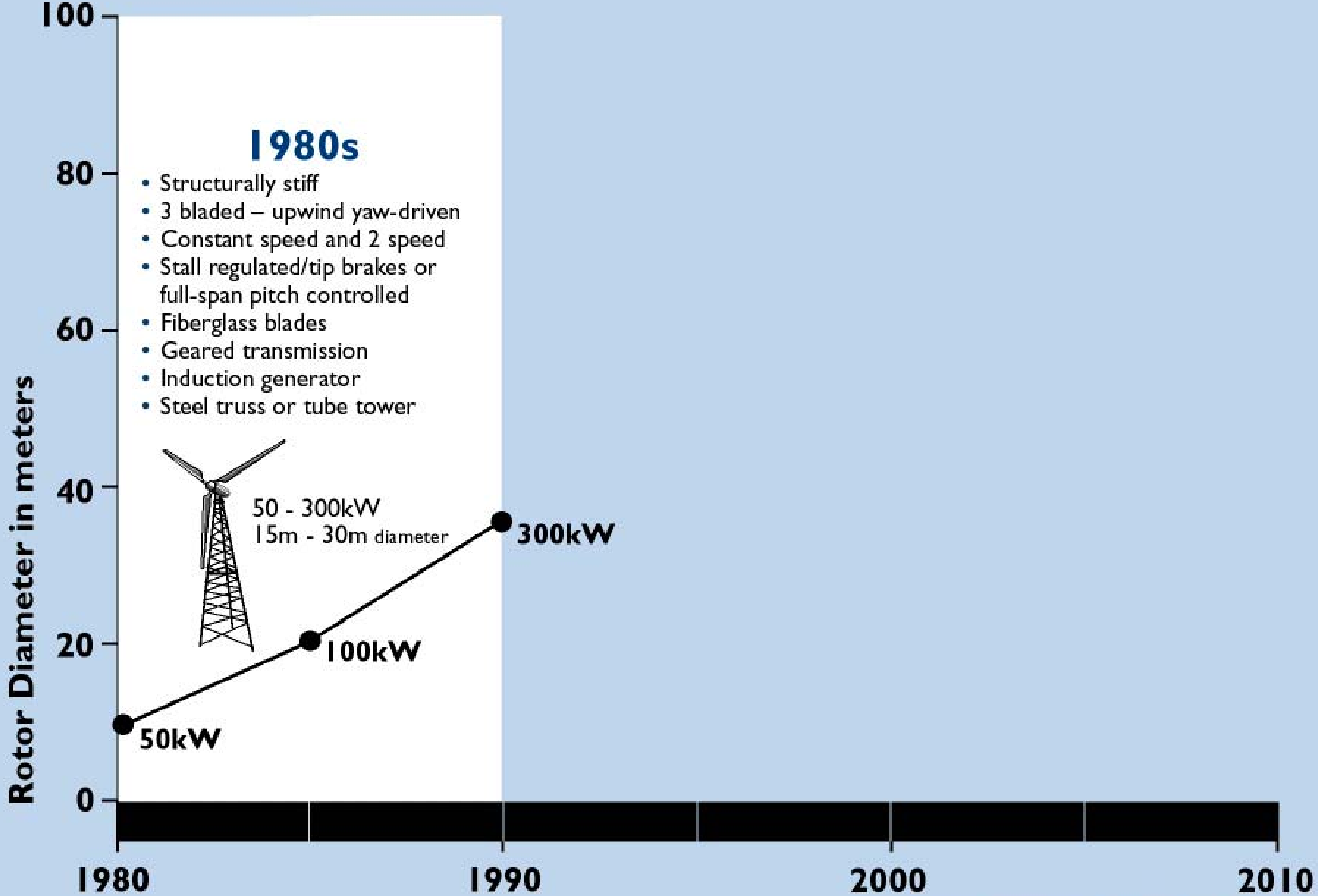
04824

Dyess Air Force Base, Texas (near Abilene)

00263

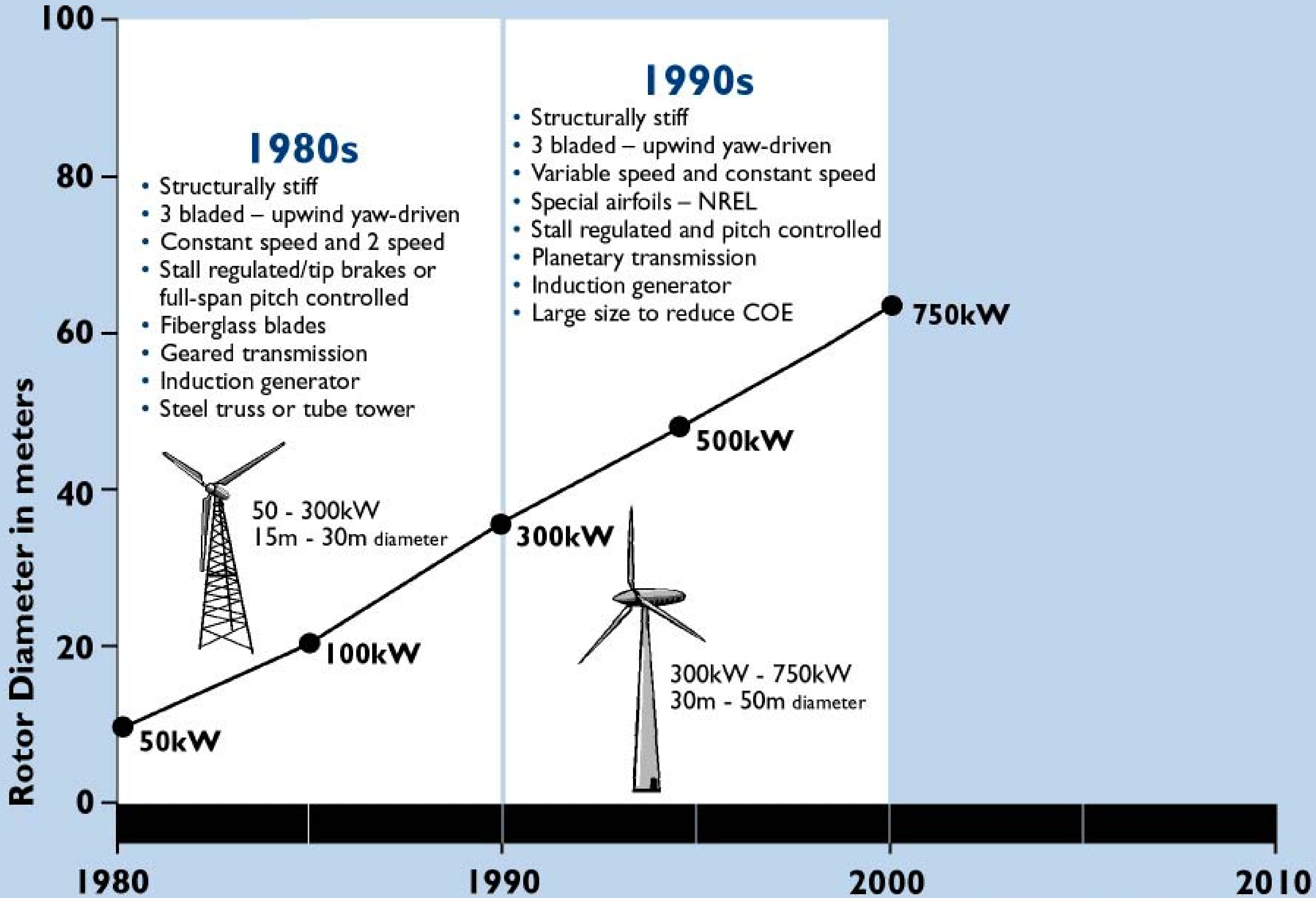
Palm Springs, CA, wind farm

THE EVOLUTION OF COMMERCIAL U.S. WIND TECHNOLOGY



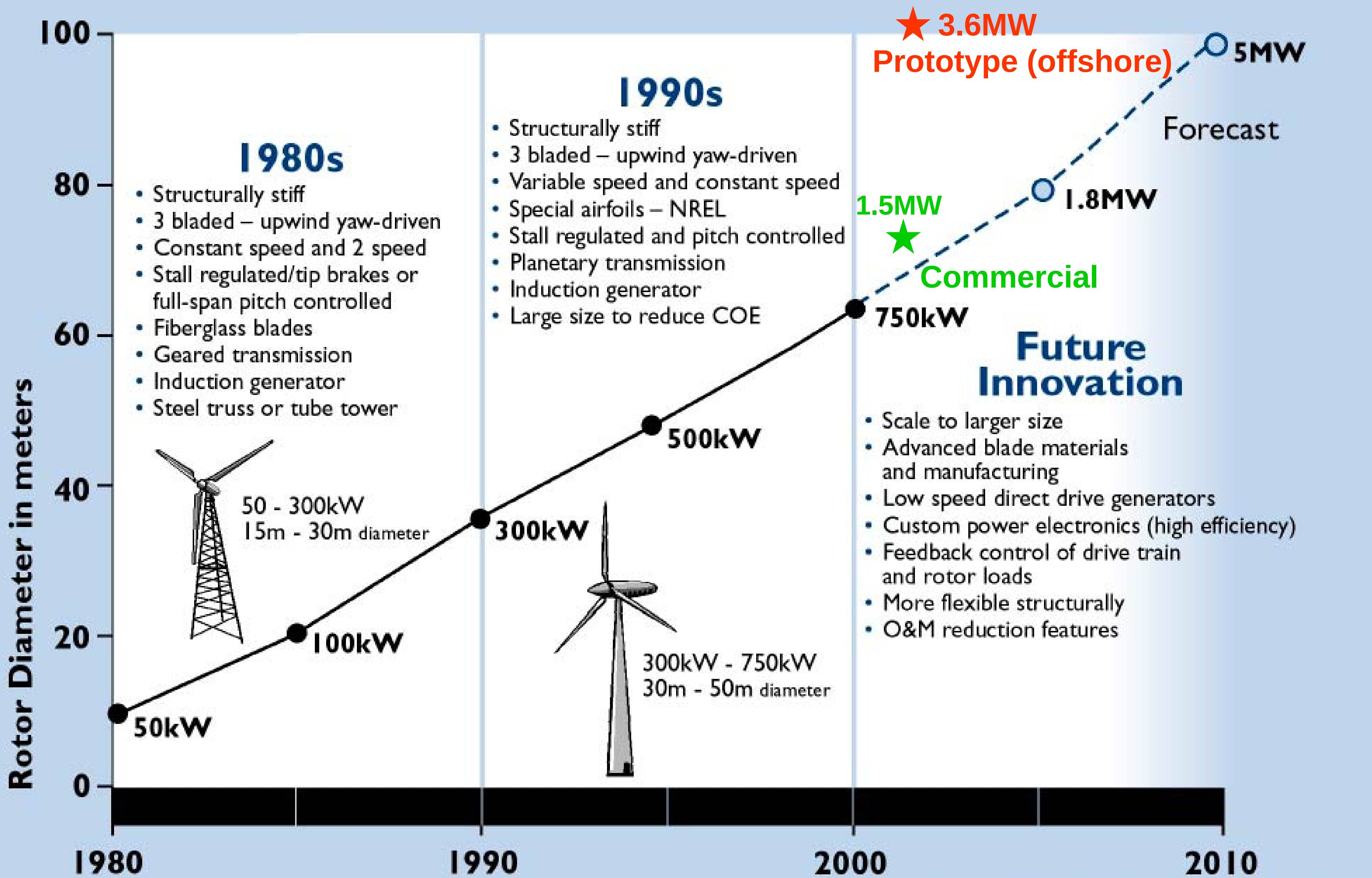
Source: Thresher & Dodge, Wind Energy Journal 1998

The Evolution of Commercial U.S. Wind Technology



Source: Thresher & Dodge, Wind Energy Journal 1998

The Evolution of Commercial U.S. Wind Technology



Source: Thresher & Dodge, Wind Energy Journal 1998

A Future Vision for Wind Energy

2003

Bulk Power Generator
3-5¢ at 15mph

- Land Based
- Bulk Electricity
- Wind Farms

Potential 20% of Electricity Market

Land Based Electricity Path

Land Based LWST
Large-Scale
2 – 5 MW

Transmission Barriers

Future

LWST Turbines:
- >3¢/kWh at 13mph
- Electricity Market

2012

Offshore Electricity Path

Offshore Turbines
5 MW and Larger

Cost and Regulatory Barriers

Offshore LWST Turbine:
- >5¢/kWh
- Shallow/***Deep*** *Water*
- Electricity Market
- Higher Wind Sites

2012 and Beyond

Advanced Applications Path

Land or Sea Based:
- **Hydrogen**
- **Clean Water**

Cost and Infrastructure Barriers

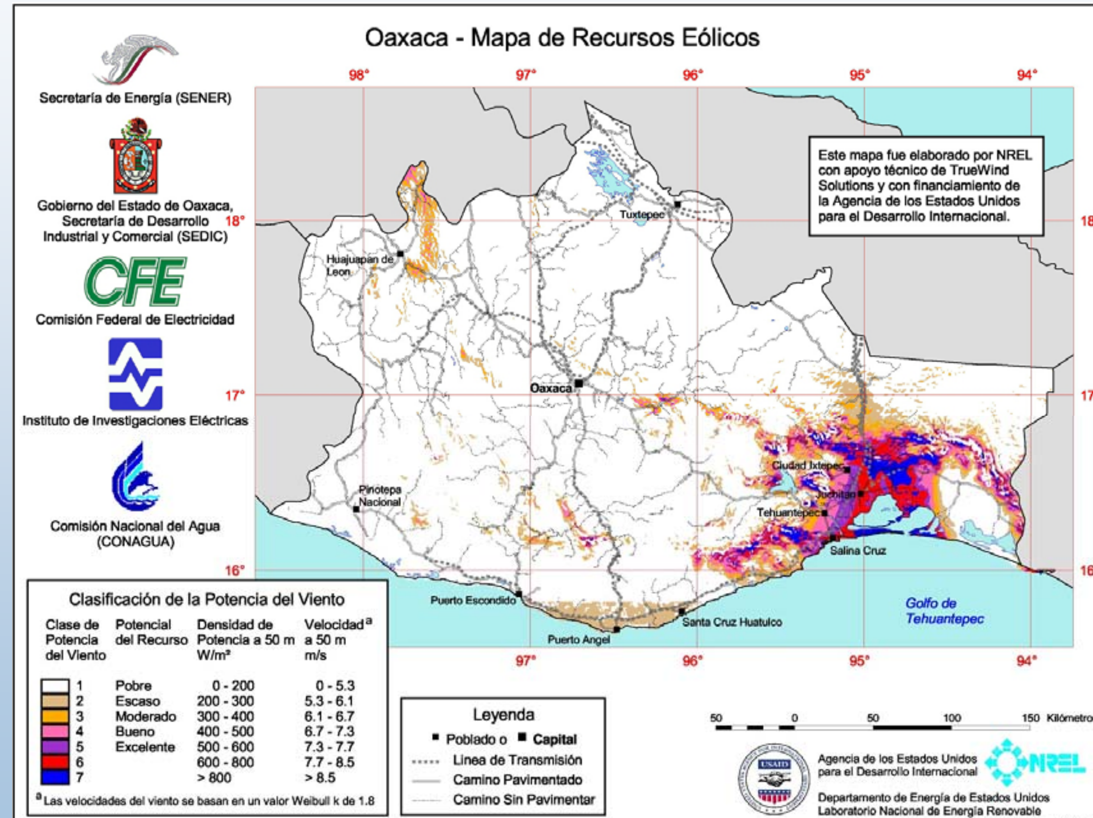
Custom Turbines:
- Electricity
- H2 production
- Desalinate water
- ? Cost
- Multi-Market

2030 and Beyond

LWST = Low wind speed turbine

US-Mexico Cooperation in Resource Assessment

- Resource Assessment
  - Critical first step
  - Increasing use of satellite data and GPS in GIS data bases



http://www.nrel.gov/international/rr_assessment.html

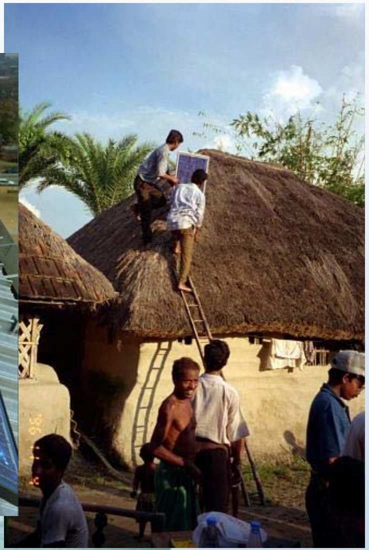
Solar Energy

04566

PV roofing shingles

PV panels

03498



04876

Indo-US Cooperative
PV Project

01026

210 kW PV system at
SMUD's Hedge substation

03396

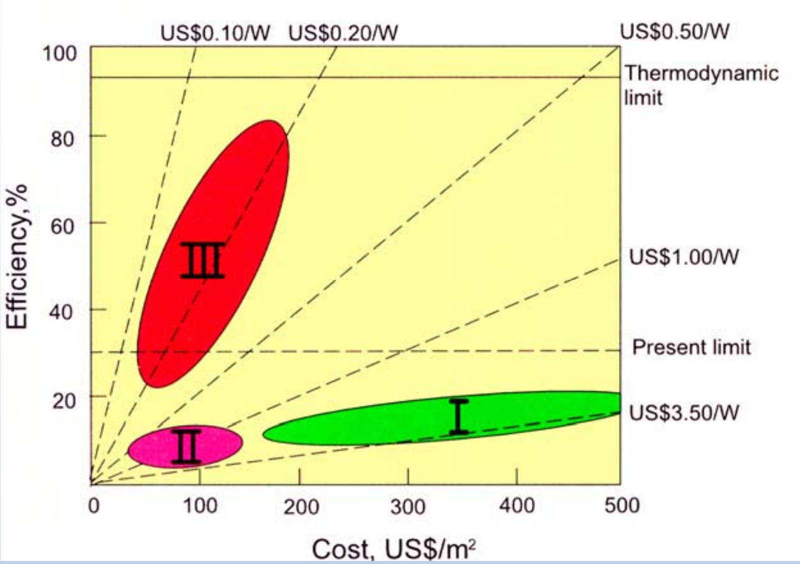
PV-powered water pumping

Moving to 3rd-Generation Solar Cells

I. 1st Generation
   - Single crystal Si
   - Poly-grain Si

II. 2nd Generation (Polycrystalline Thin Film)
   - Amorphous Si
   - Thin film Si
   - $CuInSe_2$
   - CdTe
   - Organic

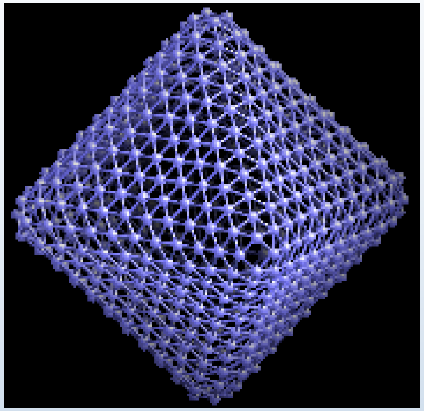
III. 3rd Generation (n_{theor}>31%; Queisser-Schockley limit)
   - Tandem cells
   - Hot electron converters
   - Intermediate band



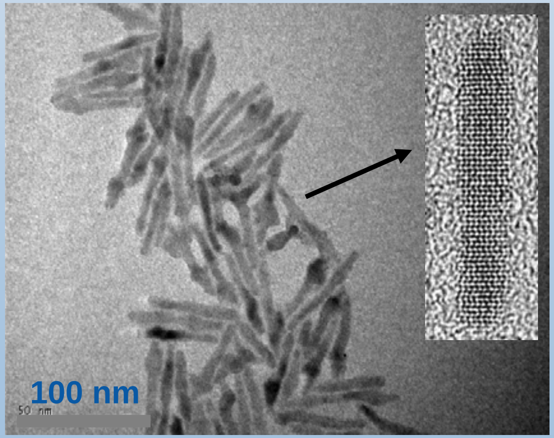
Region III indicates efficiencies higher than previous theoretical limits, at lower costs, made possible by nanostructures such as quantum dots

Next-Generation Devices and Materials

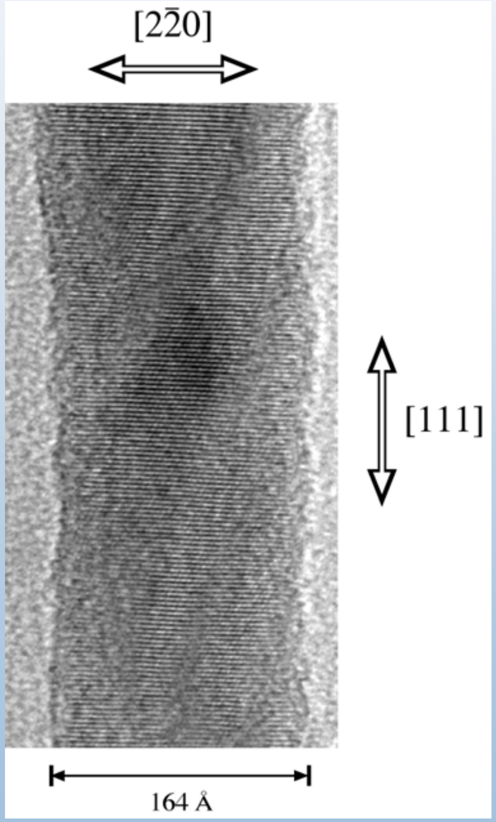
- Quantum dots and rods
- Organic polymers
- Solar hydrogen



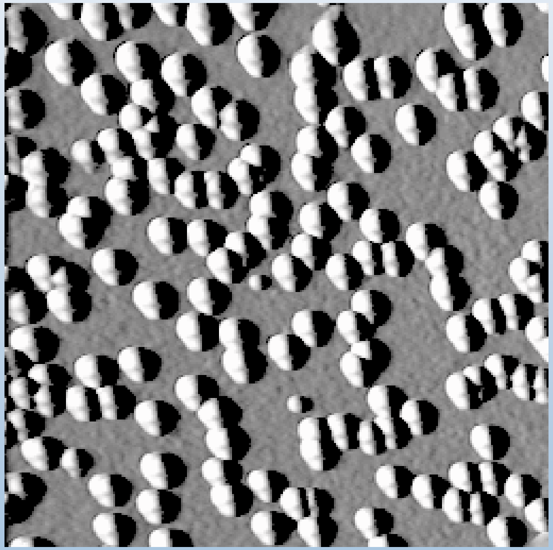
MoX_2 (X = S, Se)



CdSe nanorods in polymer



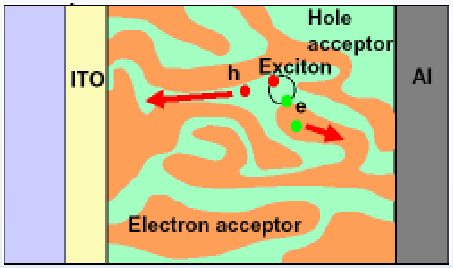
InP Quantum rods

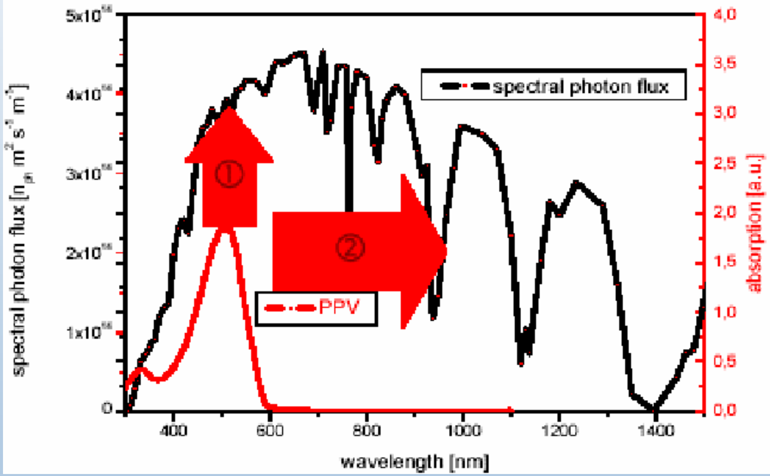


InP Quantum dots

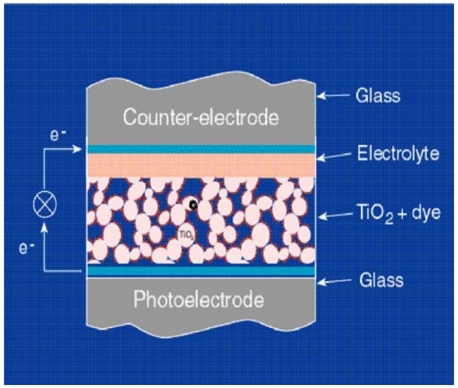
Novel Concepts, Excitonic Devices and New Materials

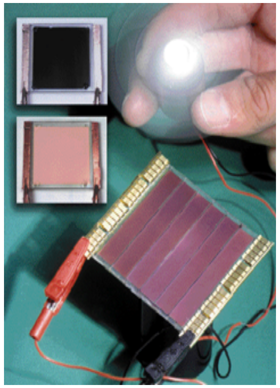
Key Companies:
GE, Kodak, Konarka, NanoSolar, NanoSys, Luna, UltraDots …





Light management	• Enhanced absorptivity of dyes • Low bandgap polymers
Reduce series resistance	• Higher mobility polymers • Enhanced TCOs • Electrolyte formulations • Polymer morphology



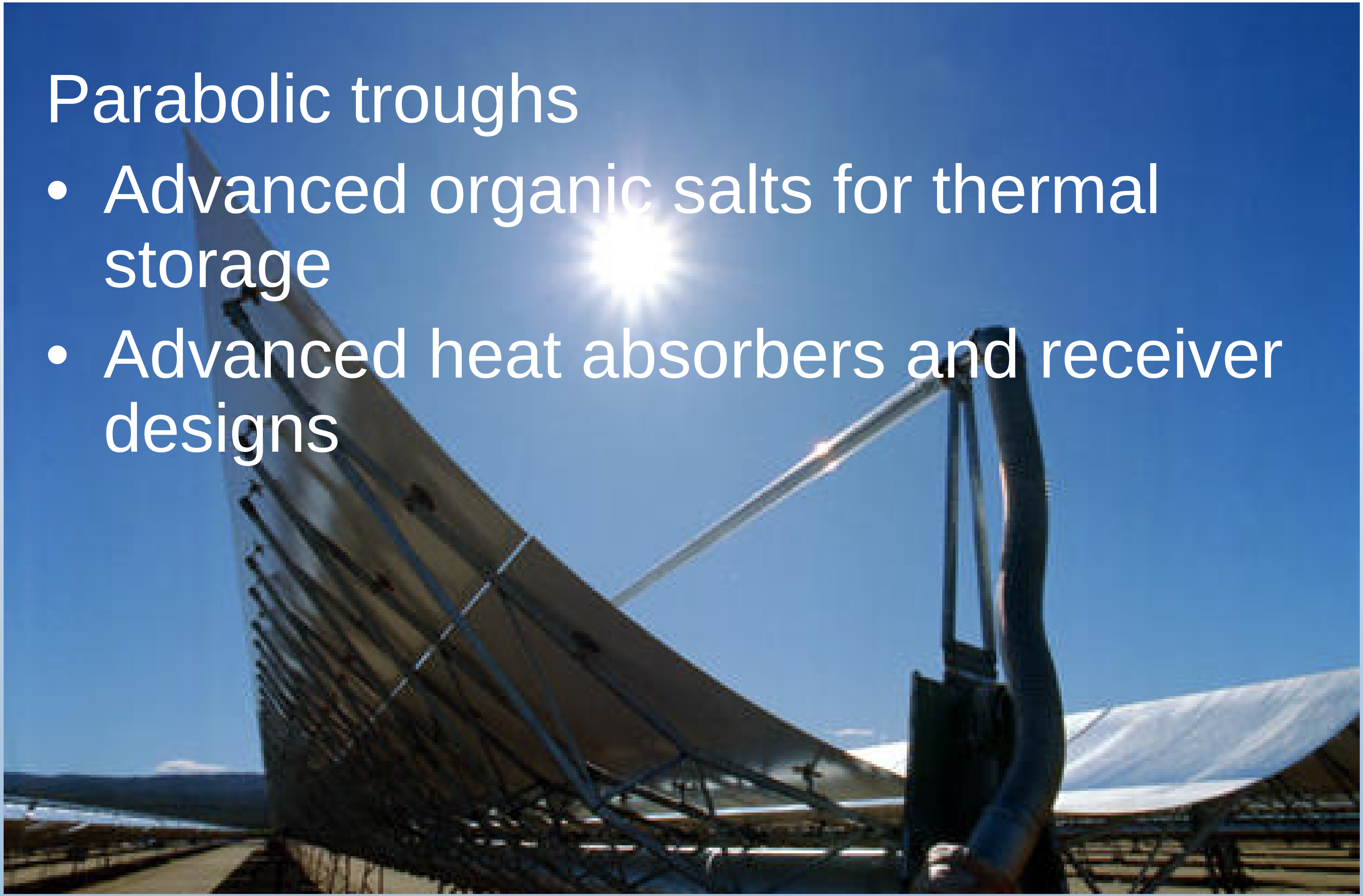


- Dye-sensitized TiO_2 photochemical cells
- Potential for very low cost
- Nanocrystalline TiO_2, with monolayer dye sensitizer,in liquid electrolyte
- 11%-efficient cell; scale-up for consumer products underway
- Dye stability issue
- Gel or solid-state electrolytes in research
- Photoelectrochromic window (with WO_3)

Concentrating Solar Power

Parabolic troughs

- Advanced organic salts for thermal storage
- Advanced heat absorbers and receiver designs



Geothermal Energy

00412

Power production from concentrated brines

Geothermal power plant at The Geysers

00060

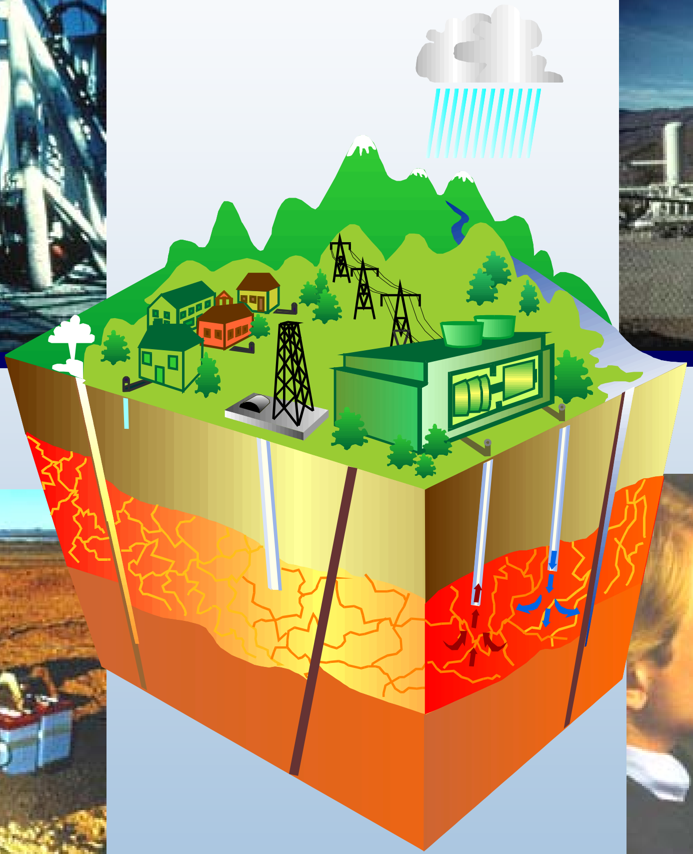
03694

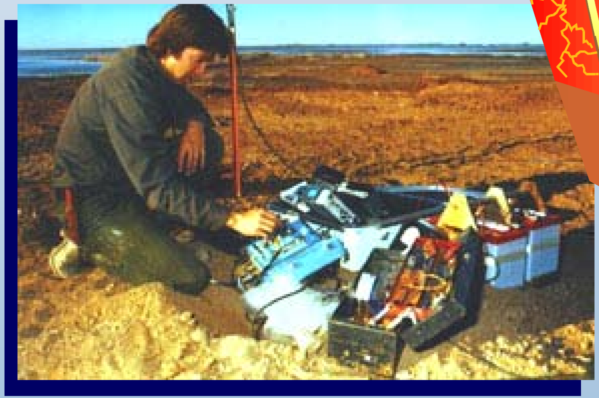
Heat exchangers and circulation pumps

Geothermal Technology

Drilling

Energy Conversion



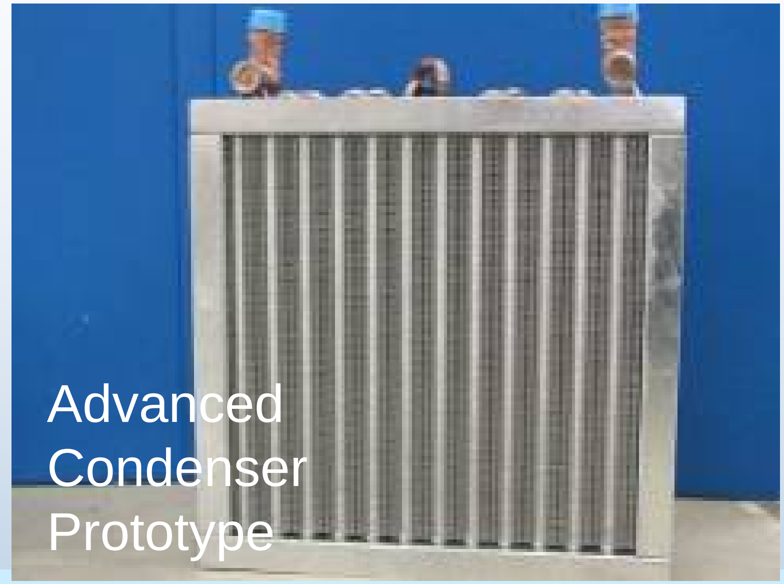


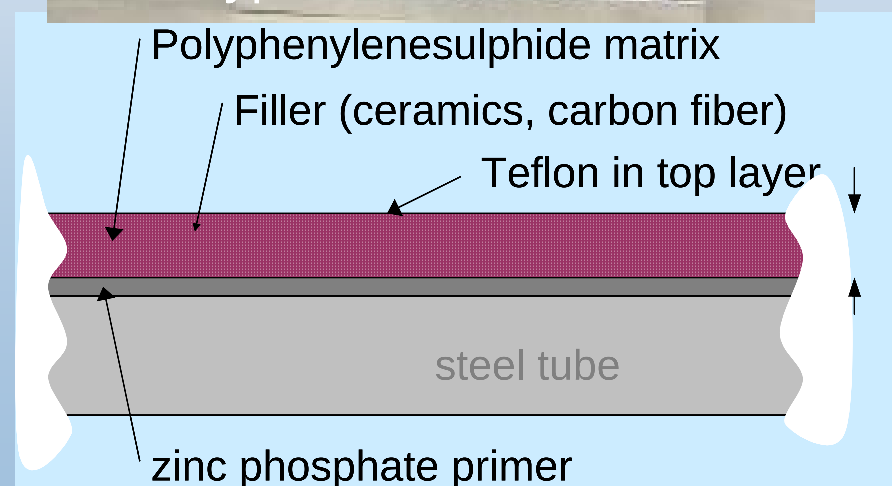
Exploration

Reservoir Technology

Next-Generation Engineered Geothermal Systems

- Improved heat exchangers
- Hybrid air/water cooling
- Improved materials
- Advanced power cycles
- Better turbines
- O&M cost reductions





Polyphenylenesulphide Coating

Biomass Sources

Wood chips

Switch grass

Poplars

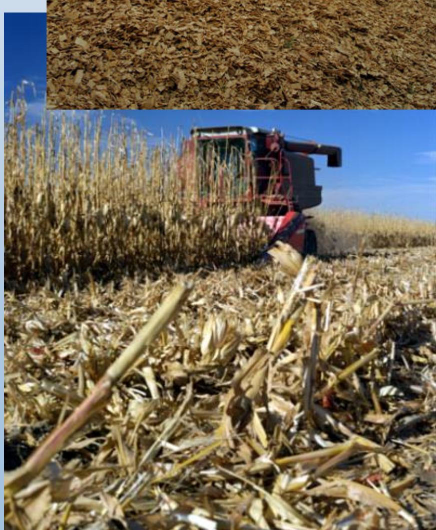
Sugar cane residue

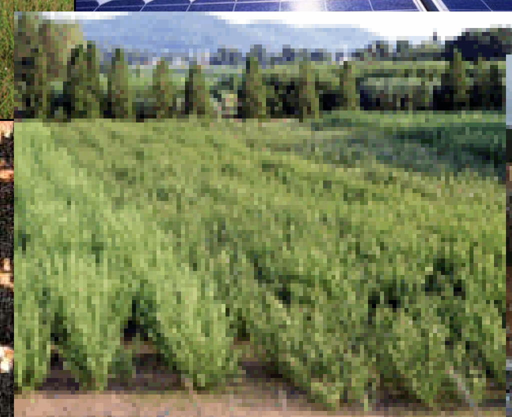
Municipal solid waste

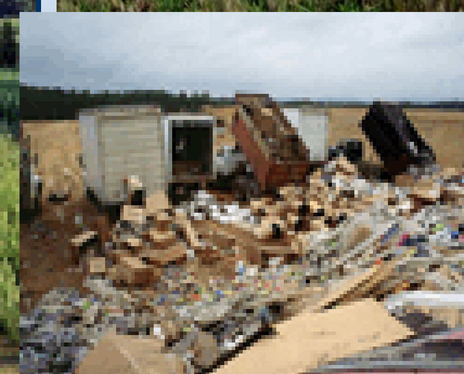
Alfalfa

The Unique Role of Biomass

While the growing need for sustainable electric power can be met by other renewables…





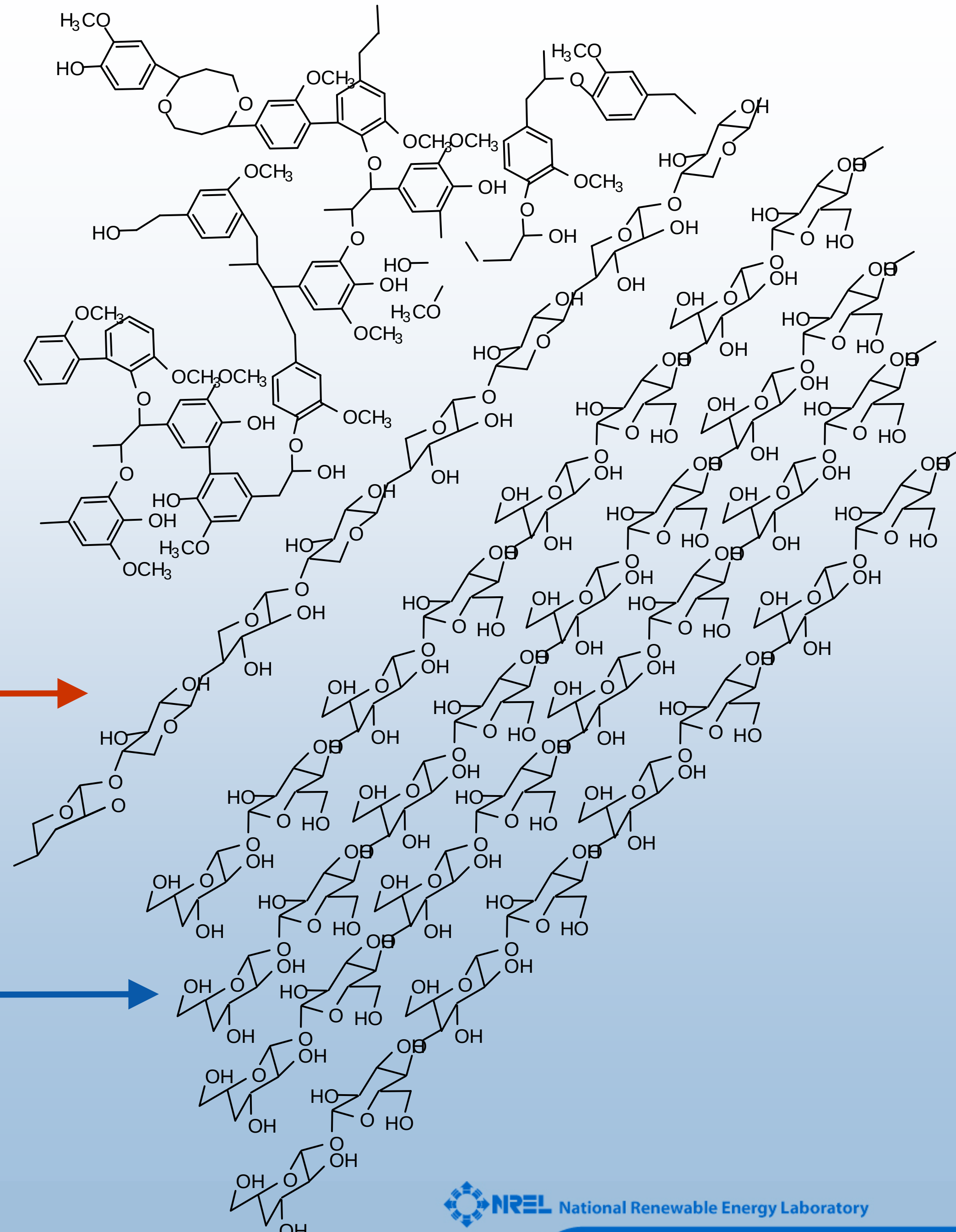


Biomass is our only renewable source of carbon-based fuels and chemicals

Biomass Chemistry

Lignin: 15-25%

- Complex aromatic structure
- Resists biochemical conversion
- Requires high temperatures to convert



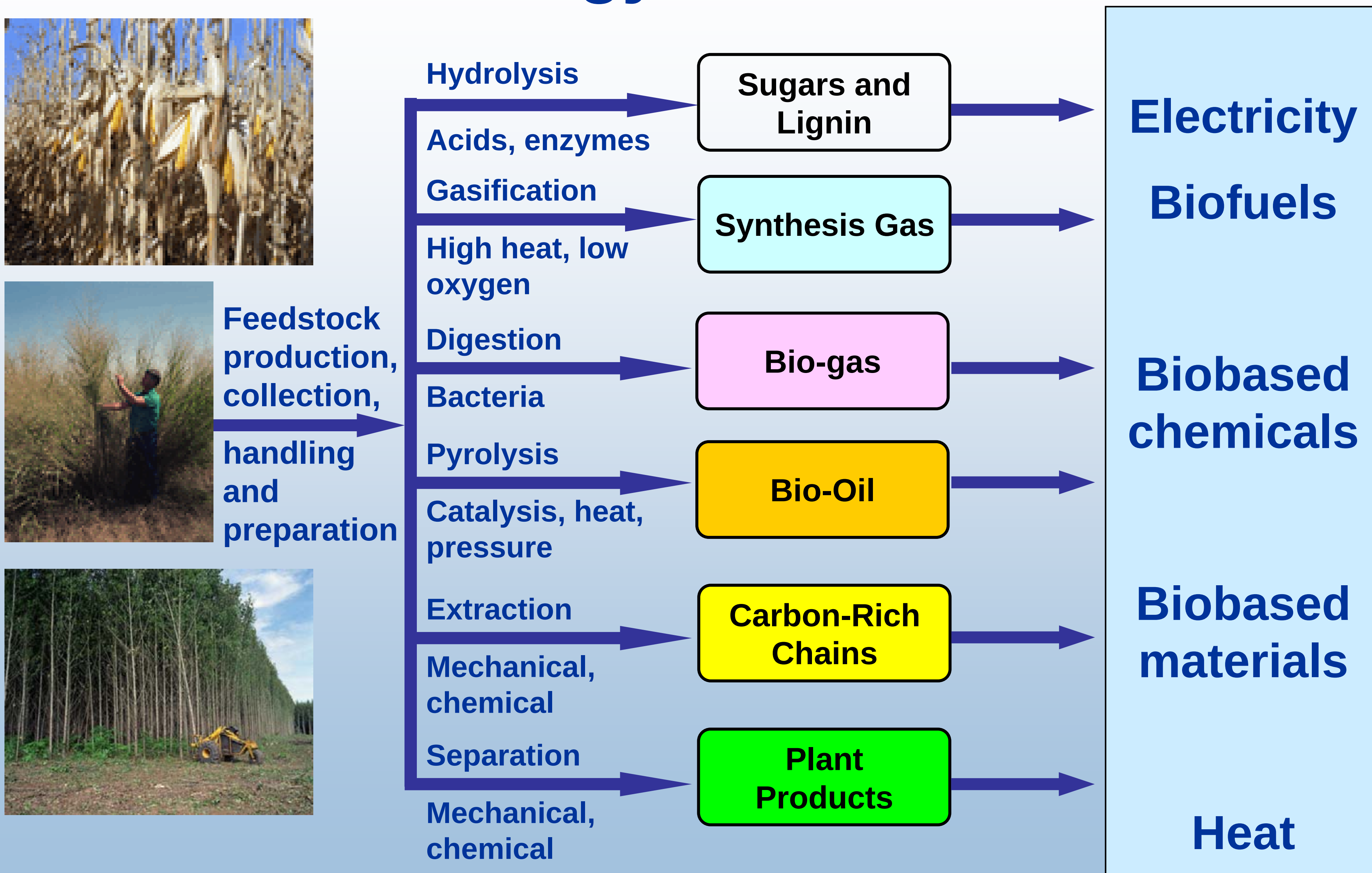
Hemicellulose: 23-32%

- Polymer of 5- and 6-carbon sugars
- Easily depolymerization
- 5-carbon sugars hard to metabolize

Cellulose: 38-50%

- Polymer of glucose
- Susceptible to enzymatic attack
- Glucose easy to metabolize

Bioenergy “Platforms”



The New Bio-Industry

Biomass Feedstock

– Trees
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste

Conversion Processes

- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Gasification
- Combustion
- Co-firing

USES

Fuels:
– Ethanol
– Renewable Diesel

Power:
– Electricity
– Heat

Chemicals
– Plastics
– Solvents
– Chemical Intermediates
– Phenolics
– Adhesives
– Furfural
– Fatty acids
– Acetic Acid
– Carbon black
– Paints
– Dyes, Pigments, and Ink
– Detergents
– Lubricants
– Etc.

Food and Feed and Fiber

… and new concepts from plants to products

Mexico Renewable Energy and Energy Efficiency Market Development

- DOE has supported work with Mexico since 1995 on technology transfer, capacity building, resource assessment, renewable energy and energy efficiency project identification and development, standards and labeling activities, and hybrid system installations
- DOE has developed close relationships with key energy and environment ministries and strong private sector partnerships.
- Rural Electrification:
  - DOE's laboratories and other partners have supported development of pilot hybrid power systems projects and promoted project replication throughout rural Mexico in collaboration with the Mexico Renewable Energy Program (MREP) *More than 400 cost-shared pilot or demonstrative systems have been installed*
  - DOE's laboratories assisting Mexico's Secretary of Energy in implementation of rural electrification program and GVEP state action plans through HOMER and options analysis training and capacity building
- Energy Efficiency:
  - LBNL through CLASP has supported APEC and NAEWG, and provided technical assistance in evaluating the impact of Mexico's standards and labeling program. *Mexico reported estimated energy savings of 2500 GWh, ~7% of Mexico's residential electricity as impact from S&L program.*
  - NREL and CONAE ESCO Program for Hotel and Industrial Sectors helped facilitate *3 US/Mexico partnerships with a total value of $60 Million USD, conducted over a dozen facility audits, and provided training to 20 US and Mexican ESCOs and more than 80 energy end-users*
- Key to success has been focus on public-private partnerships, staying engaged in specific market niche for several years, and transfer of key knowledge and technology to support the market needs

Renewable Energy Costs – Electricity

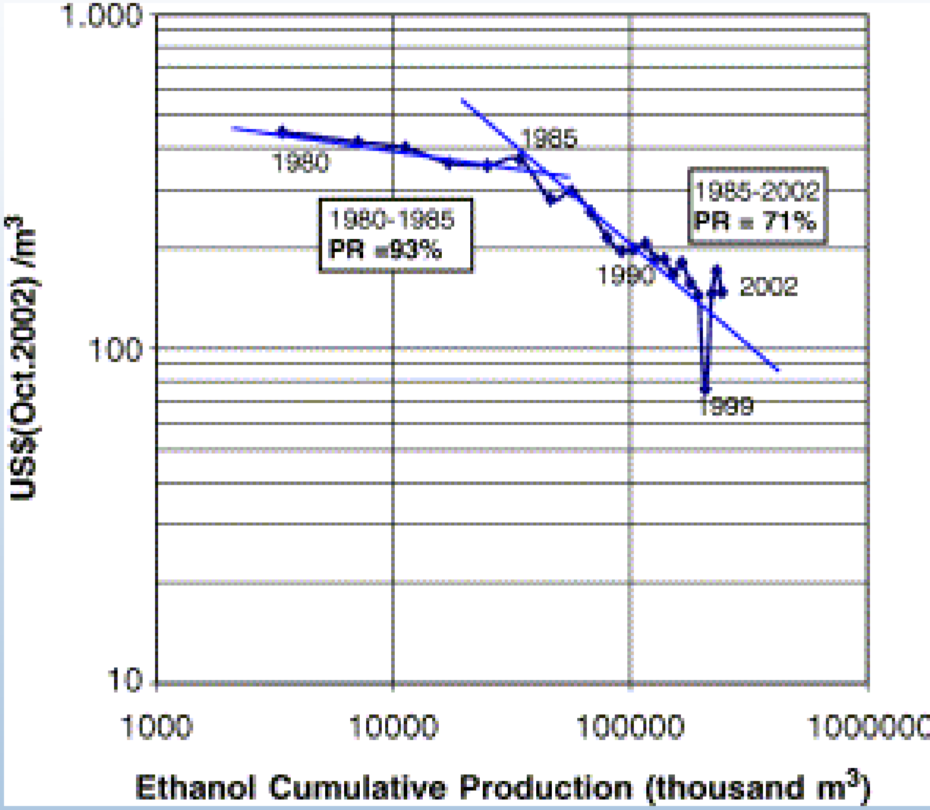
	Costs (¢/ kWh)		
Technology	Today	2010	2020
Wind	3–5¢ @ 15 mph	3¢ (2012) @ 13 mph	5¢ (> 2012) offshore
Solar			
PV	24–30¢	12–14¢	6–8¢
CSP	10¢	6¢	4–5¢
Geothermal	5–8¢	3–5¢ (2007)	–

Renewable Energy Costs – Fuels

	Costs c/L ($/ USgal ethanol)		
Technology	Today	2010	2020
Biomass	64.5 (2.50)	46.4 (1.80)	27.6 (1.07)

Learning by Doing

- Progress and learning curves
  - As important to the diffusion of technology as RD&D
  - Key outcome of initial incentives – that is… if it is a *Wise subsidy*



J Goldemberg, ST Coelho, PM Nastaric, O Lucon. *Ethanol learning curve the Brazilian experience*
Biomass and Bioenergy 26(3) pp 301-304

Final remarks

- The global and CANUSAMEX technical resources >> projected global/regional energy demand
- Technology progress continues to be rapid
  - Learning curve effects for PV, Wind and Ethanol are significant sources of cost reduction
- Economic Potential is a function of policy and pricing of fossil fuels – annual growth rate?
  - BAU forecasts (ex Hydro) are for 2.6% growth
  - IEA-Ren forecast has a growth rate of 3.6%
  - Needed global growth rate depends on final CO2 equilibrium min = 4.6% (for 550 ppm) and > 6% (for 350 ppm)

The U.S. Department of Energy's

National Renewable Energy Laboratory

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